Special Considerations

Abstract

Attachment C is intended to incorporate new seismic technology that might be of specific use in bridges. Seismic isolation is one alternative that has not been used extensively at Caltrans, but should be considered as an option. It is possible that the future might embrace this technology with competitive economics that enable the designer to choose that alternative more freely. Also discussed in this attachment is the curvature analysis/displacement capacity approach that should be considered as an alternative to the prescribed moment ductility retrofit analysis procedure.

Seismic Isolation

Seismic Isolation is a method to reduce seismic loadings applied to a structure through added flexibility and energy dissipation. Additional flexibility lengthens the natural period of a structure along the acceleration response spectrum. The lengthened period can significantly reduce seismic forces to a level which approaches elastic capacity for structures founded on rock or in compact granular soils. Thus, damage can be averted and structures can remain serviceable following a major seismic event. Relative displacements between substructure and superstructure can be limited to a practical design level by controlling damping and energy dissipation characteristics of isolators.

A bridge where the superstructure is supported by rocker type bearings is a good example of a Seismic Isolation retrofit candidate. Installation of Seismic Isolation bearings at hinge locations at the top or bottom of multi-column bent structures is also possible. By replacing the existing bearings with Seismic Isolation bearings, force levels could be reduced to the point that no substructure retrofit be required. Therefore, isolation is particularly attractive where conditions at the base of the pier prohibit, or significantly impede, common retrofit schemes. Such conditions are: traffic lanes which can't be closed, vital utilities, restricted right-of-way, buildings, water, environmentally sensitive areas, etc. There are times when isolation is most economical, but other constraints may dictate use of isolation, even if that solution is not the most economical.

Regardless of motivation for choosing isolation, the designer must provide for resulting displacements at abutments and intermediate joints. Total superstructure movement is comparable to a monolithic structure, however, the majority of the movement occurs at the isolator rather than in column deflections.

The non-linear hysteretic behavior of the bearing can be modelled in STRUDL by using a composite response spectrum. This spectrum is combined with the Caltrans ARS Spectrum for 5% damping for the non-isolated modal responses and a modified spectrum for isolated modes that reflect the 20–30% hysteretic damping of the isolation bearing.

Specifications have been developed that generically describe the performance and material requirements for the Isolation bearings. These specifications refer to the structural plans for limiting force and displacement characteristics, and the hysteretic behavior of the bearing.

As a precaution, isolation should generally be avoided when structures are found in soft soil because long period characteristics of such soils can get in resonance with the structure. Also, when structures have intermediate hinges (articulated), isolation may create detrimental effects. Both of these situations can be accommodated, but the designer must produce more intensified, complex analysis computations.

References for the practical use of isolation in bridge seismic design are given below:

1. "Seismic Isolation and Energy Dissipation, Implementation in Bridge Analysis and Design," Dynamic Isolation Systems, December 1990.

2. "PC Leader - Design of Lead Rubber Force Control and Seismic Isolation Bearing," Dynamic Isolation Systems (a PC computer design program), October 1990.

3. "AASHTO Guide Specifications for Seismic Isolation Design," June 1991.

The designer should be aware of circumstances where isolation looks appropriate, practical, and economical. The proposal should be introduced at the strategy meeting. The strategy panel will judge the appropriateness of the isolation option, keeping in mind the cautions expressed by the Seismic Advisory Board.

The following paragraph summarizes the views of Caltrans Seismic Advisory Board on the use of seismic isolation for bridges.

> "Base isolation can be used effectively to reduce seismically induced forces on a structure provided 1) the isolation system has suitable force-displacement and damping properties which will be maintained over the life of the structure; and

2) the system will remain stable under the combined dead and seismic loadings during a maximum expected event so that the overall system can safely tolerate the associated large shear **displacements** produced in the isolation system. Since the use of base isolation increases the fundamental period of an overall structural system, the peak free-field ground acceleration is no longer a critical parameter to the seismic response. In this case peak free-field ground velocity becomes more critical and, with sufficient increase in period, the peak free-field ground displacement becomes the most critical parameter. Therefore, the longer period components of the free-field ground motion used as a basis for design must be selected with special care. The installation of base isolation on existing elevated and articulated viaducts is considered to be inappropriate. The Board recommends that Caltrans proceed cautiously with any experimental program of installing base isolation on other existing bridges and that it consider all of the above factors in selecting isolation techniques and specific structures to be treated. Similar caution should be exercised in designing base isolation measures for new construction. Because of the sensitivity of base isolated structures to the longer periods of free-field ground motion, seismic isolation should be avoided at soft sites such as those on San Francisco Bay fill."

The Advisory Board's views should be considered a serious caution, but in no way a rejection of seismic isolation. We must choose the most appropriate retrofit solution which should include consideration of seismic isolation. Only controversial installation proposals, as determined by the strategy panel, must be studied and judged by the Advisory Board.

Curvature and Displacement Ductility

This alternative to the moment ductility retrofit analysis procedure is preferred for most situations. Often this procedure will allow a significant reduction or elimination of retrofit effort. Some of the situations where this procedure can be very valuable are:

a. Low seismic areas: bridges in low seismic areas which are showing moderate to large ductility demands by the moment ductility demand method should be analyzed with this alternative.

b. Borderline retrofit cases: bridges which have borderline moment ductility demands, regardless of the seismic area, should be investigated with this alternative.

c. Do-nothing cases: some bridges are deleted from the program via strategy meetings because they appear to have sufficient load paths to prevent collapse despite moderate column ductility demands. This alternative provides a good means to assure displacement capacity for this situation.

d. Moderate spiral reinforcement: Some existing columns have moderate spiral reinforcement (i.e., #5@ 6") which should be adequate to assure moderate displacement capacity.

Figure C1 shows a flowchart of all steps used in the analysis/check of the transverse response of a typical multi-column bent.

The designer must remember that the guidelines are based on limited analyses and relatively simple structures (i.e., no curves or skews). The guidelines should not be followed blindly. Earthquake investigations indicate that longitudinal differential movement at hinges can be large, but not as large as ARS longitudinal displacements (use compression model longitudinal displacements). Therefore, the designer must use judgment when establishing longitudinal displacement demands.

Geometric shape can also have some effects. For curved bridges, the designer cannot investigate a single bent without considering effects of adjacent bents in the same frame. The curved frame will act as a "milk stool" and will tend to develop cyclic axial loads even for single-column bents. Also, if frames have columns with significantly different stiffness (i.e., 20%), the procedure should be applied to the frame and not to individual columns.

As designers use this method more often, problems and discoveries will be monitored. New data will be passed along to designers and processes will be updated.

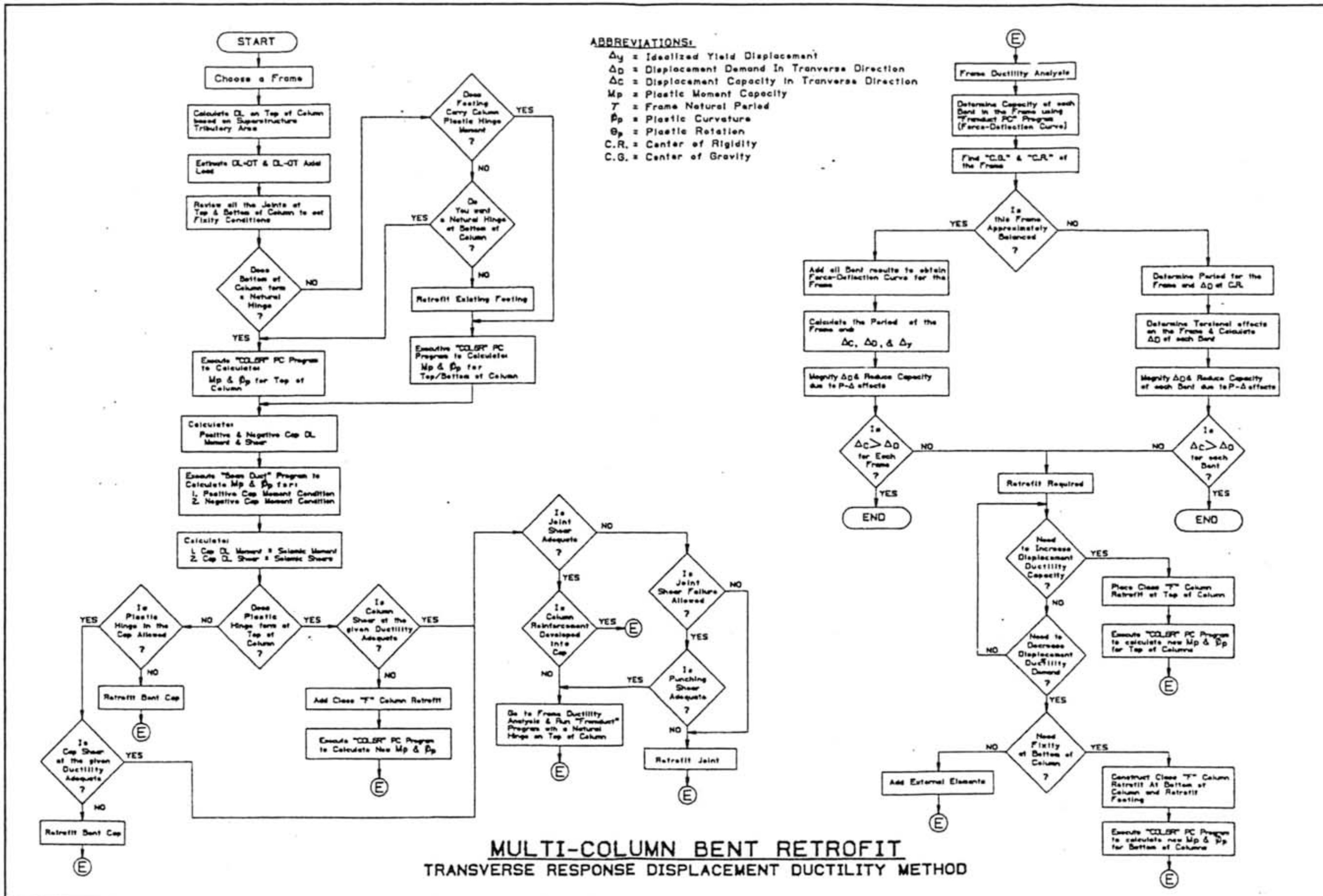
ABBREVIATIONS:
Δy = Idealized Yield Displacement
ΔD = Displacement Demand In Tranverse Direction
ΔC = Displacement Capacity In Tranverse Direction
Mp = Plastic Moment Capacity
T = Frame Natural Period
φp = Plastic Curvature
θp = Plastic Rotation
C.R. = Center of Rigidity
C.G. = Center of Gravity
START
Choose a Frame
Calculate DL on Top of Column based on Superstructure Tributary Area
Estimate DL-OT & DL-OT Axial Load
Review all the Joints at Top & Bottom of Column to set Fixity Conditions
Does Bottom of Column form a Natural Hinge ?
YES
NO
Does Footing Carry Column Plastic Hinge Moment ?
Do You want a Natural Hinge at Bottom of Column ?
Retrofit Existing Footing
Execute "COLSR" PC Program to Calculate Mp & φp for Top of Column
Execute "COLSR" PC Program to Calculate Mp & φp for Top/Bottom of Column
Calculate: Positive & Negative Cap DL Moment & Shear
Execute "Beam Duct" Program to Calculate Mp & φp for: 1. Positive Cap Moment Condition 2. Negative Cap Moment Condition
Calculate: 1. Cap DL Moment ± Seismic Moment 2. Cap DL Shear ± Seismic Shears
Is Plastic Hinge in the Cap Allowed ?
Does Plastic Hinge form at Top of Column ?
Is Column Shear at the given Ductility Adequate ?
Retrofit Bent Cap
Add Class "F" Column Retrofit
Execute "COLSR" PC Program to Calculate New Mp & φp
Is Cap Shear at the given Ductility Adequate ?
Retrofit Bent Cap
Is Joint Shear Adequate ?
Is Column Reinforcement Developed Into Cap ?
Go to Frame Ductility Analysis & Run "Fremduct" Program with a Natural Hinge on Top of Column
Is Joint Shear Failure Allowed ?
Is Punching Shear Adequate ?
Retrofit Joint
E
Frame Ductility Analysis
Determine Capacity of each Bent in the Frame using "Fremduct PC" Program (Force-Deflection Curve)
Find "C.G." & "C.R." of the Frame
Is this Frame Approximately Balanced ?
Add all Bent results to obtain Force-Deflection Curve for the Frame
Calculate the Period of the Frame and ΔC, ΔD, & Δy
Magnify ΔD & Reduce Capacity due to P-Δ effects
Is ΔC > ΔD for Each Frame ?
END
Determine Period for the Frame and ΔD at C.R.
Determine Torsional effects on the Frame & Calculate ΔD of each Bent
Magnify ΔD & Reduce Capacity of each Bent due to P-Δ effects
Is ΔC > ΔD for each Bent ?
Retrofit Required
Need to Increase Displacement Ductility Capacity ?
Place Class "F" Column Retrofit at Top of Column
Execute "COLSR" PC Program to calculate new Mp & φp for Top of Columns
Need to Decrease Displacement Ductility Demand ?
Need Fixity at Bottom of Column ?
Add External Elements
Construct Class "F" Column Retrofit At Bottom of Column and Retrofit Footing
Execute "COLSR" PC Program to calculate new Mp & φp for Bottom of Columns
MULTI-COLUMN BENT RETROFIT
TRANSVERSE RESPONSE DISPLACEMENT DUCTILITY METHOD

Figure C1